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Laboratory Tests of an Electrical Barrier for Controlling Predation by Northern Squawfish

By

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and
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ABSTRACT

Northern squawfish (Ptychocheilus oregonensis) prey extensively on the young of sport and commercial fishes. Of particular concern to us was their heavy predation during early spring and summer on salmon (Oncorhynchus spp.) that are released from upstream hatcheries on the Columbia River and must pass through squawfish-infested areas on their way to the sea. Control of these predators entailed finding a means of blocking their passage into the release areas of the hatchery-reared salmon without interfering with the outmigration. For this purpose, we explored in the laboratory the effectiveness of electrical fields previously found to direct the movements of salmon fingerlings.

Electrical fields were produced by two rows of hollow aluminum electrodes suspended in the water across a laboratory tank. Exploratory tests were run to determine what combinations of electrode arrays, voltage gradients, and electrical conditions would give results warranting systematic testing. Ten fish were tested individually in each of these elimination tests.

On the basis of test results, four electrode arrays, with capacitor discharge pulses at 8 pulses per second and a pulse duration equivalent to that of 40 millisecond "rectangular pulse," were tested at three voltage gradients. A staggered array of electrodes in which the electrodes were spaced at 61-cm. intervals in rows 200 cm. apart was most effective. At the voltage gradients of 0.75, 1.00, and 1.25 volts per centimeter, 85, 93, and 96 percent respectively, of the squawfish were blocked.

INTRODUCTION

The northern squawfish, a fresh-water species in streams and lakes, has been widely reported to prey on the young of Pacific salmon, Oncorhynchus spp., and other desirable sport and food fishes (see, for example, Carl and Clemens, 1948; Foerster, 1937, 1938; Foerster and Ricker, 1941; and Ricker, 1941).

In the lower Columbia River, predation by adult northern squawfish on salmon fry and fingerlings from hatcheries has been noted in the areas of release (Thompson, 1959). Extensive predation has been observed at the Little White Salmon station on the Little White Salmon River, about 1.6 km. above its confluence with the Columbia River (fig. 1). The construction of Bonneville Dam resulted in the inundation of the lower half of Little White Salmon River and the formation of an embayment that is now referred to as Drano Lake. Predation is particularly extensive while hatchery fish are passing through this lake.[1]

In 1953 we set gill nets to determine the abundance and movements of northern squawfish in Drano Lake before and during releases of fry and fingerlings of chinook salmon, O. tshawytscha, into the lake. Catches demonstrated that the population of squawfish was fairly stable during February and April but that squawfish moved into the lake from the Columbia River during May and June, after the hatchery releases. Thus, controlling the squawfish would involve not only the reduction of the winter population, but also the control of their immigration into Drano Lake from the Columbia River during the period of hatchery releases.

[1] Zimmer, Paul D. 1953. Observations on hatchery releases and squawfish predation in Little White Salmon River in spring of 1953. U.S. Fish Wildl. Serv., Portland, Oreg., 14 pp. [Processed.]

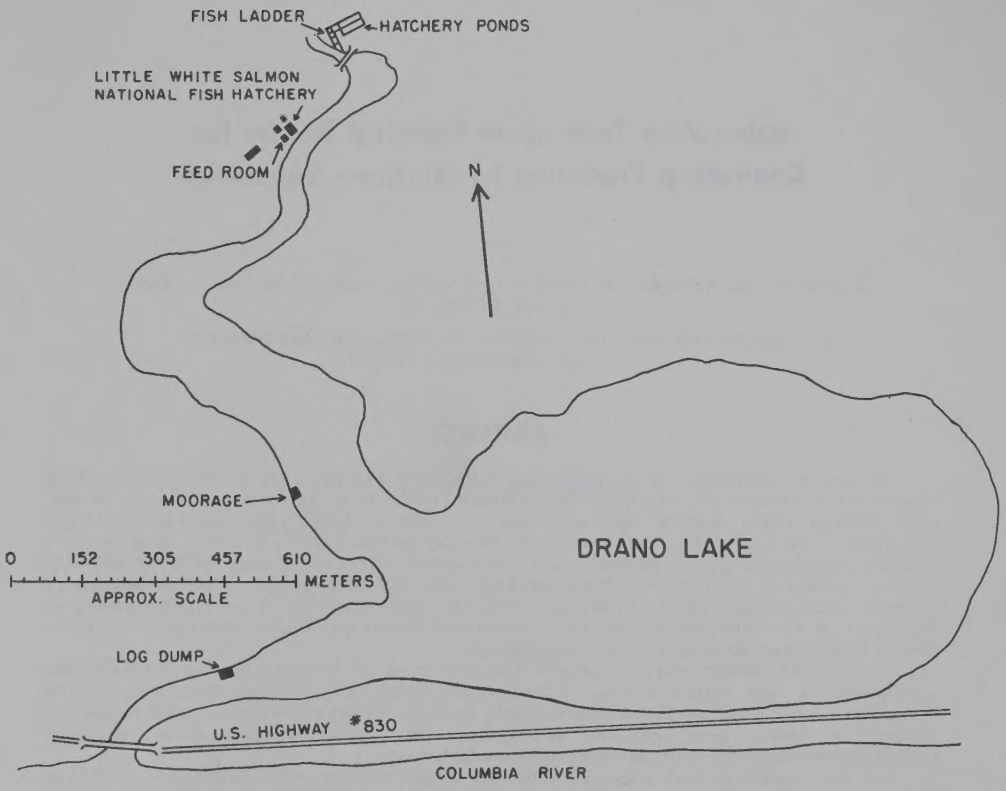


Figure 1.--Map of Drano Lake and migration route of juvenile salmon from Little White Salmon National Fish Hatchery to the Columbia River.

In an attempt to find a method of controlling or eliminating the northern squawfish in such areas as Drano Lake, we designed laboratory tests to determine the effectiveness of various electrical fields in blocking the passage of adult squawfish while permitting the passage of salmon fingerlings. The tests were made August 18-28, 1953, at the BCF (Bureau of Commercial Fisheries) Biological Laboratory, Seattle, Wash. The electrical fields produced were based on electrical stimuli that had been previously tested and found to direct the movements of salmon fingerlings.[2]

MATERIALS AND METHODS

The experimental area was a portion of a large insulated tank, constructed for studies of electrical guiding of salmon fingerlings. The tank's concrete floor and construction-block walls were covered with an electrically insulated lining of several coats of blue Amercoat[3] paint. In inside dimensions, the experimental area was 8.8 m. long, 3.2 m. wide, and 25 cm. deep. The water depth was about 18 cm.

The problem was to create electrical conditions that would be effective either in preventing squawfish from entering the electrical field or in blocking the progress of the fish once they had entered the field, while permitting the salmon fingerlings to pass through unharmed. The factors for consideration were:

1. The spacing between electrodes in each row.
2. The arrangement of the electrodes in the two rows.
3. The distance between the two rows of electrodes.

[2]Collins, G.B., C.D. Volz, and R.H. Lander. 1953. The effectiveness of pulsating direct current in controlling the movement of salmon fingerlings. Bur. Comm. Fish. Biol. Lab., Seattle, Wash. (Unpublished manuscript.)

[3]Trade names referred to in this publication do not imply endorsement of commercial products by the Bureau of Commercial Fisheries.

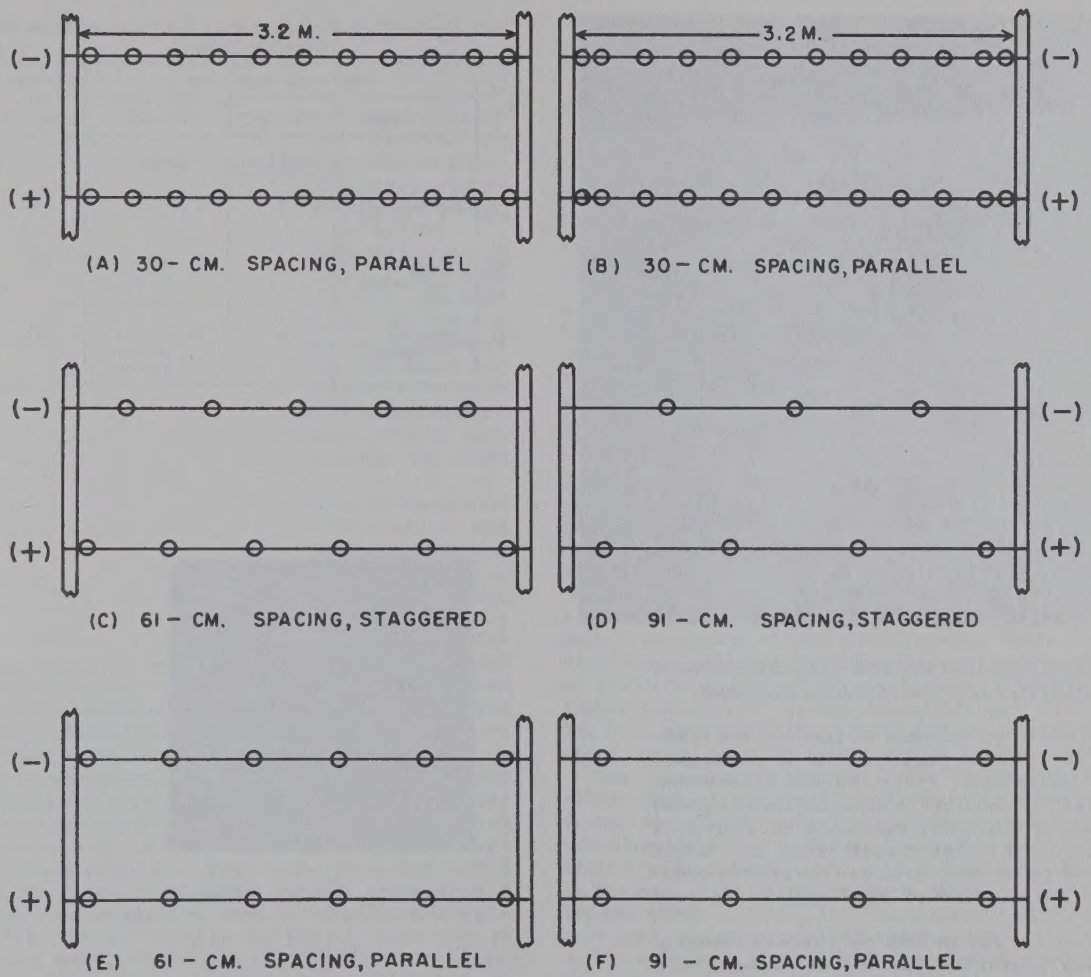


Figure 2.--Electrode arrays used in experiments.

4. Voltage gradient.
5. Effectiveness of three sets of electrical conditions including two pulse shapes when combined with the above factors.

The electrical field was in the center of the experimental area and was generated through two rows of hollow aluminum electrodes, each 5 cm. in outside diameter and 30 cm. long. The electrodes were suspended in the water from two parallel wires secured to insulators and strung at right angles across the experimental channel. They were attached to these wires by two lengths of No. 14 copper insulated wire soldered into an alligator clip at one end and fastened at the other end by bolts through holes drilled in the electrodes. The electrodes hung in the water to an approximate depth of 15 cm. (i.e., to about 3 cm. above the bottom) and were spaced 30, 61, or 91 cm. apart in parallel or staggered arrays (fig. 2 and table 1).

Table 1.--Description of electrode arrays used in exploratory and systematic tests for blocking adult northern squawfish

Electrode array	Electrode pattern	Electrodes in each row (+)	Electrodes in each row (−)	Distance between electrodes: Within rows	Distance between electrodes: Between rows
		No.	No.	Cm.	Cm.
A	Parallel	11	11	30	100
B	Parallel	12	12	30	100
C	Staggered	6	5	61	100, 200
D	Staggered	4	3	91	200
E	Parallel	6	6	61	200
F	Parallel	4	4	91	200

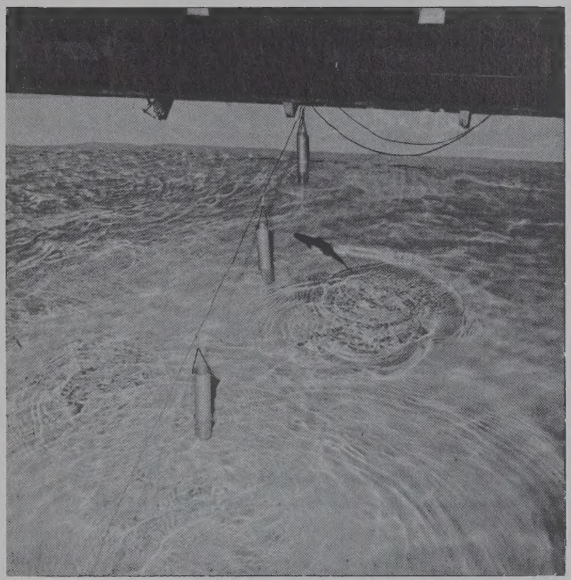


Figure 3.--Adult northern squawfish being deflected out of electrical field near row of positive electrodes.

Squawfish were introduced into the end of the channel nearest the positive row of electrodes to take advantage of the known directional properties[4] of the field in blocking the progress of the fish. If the electrical fields were actually directional, any fish penetrating the fields would tend to become oriented toward the positive row of electrodes and be deflected out (fig. 3).

Distances of 100 or 200 cm. between rows of electrodes permitted the use of voltages well below the capacity of the generator. We computed the voltage gradients by dividing the total voltage by the distances between the two rows of electrodes.

The following three sets of electrical conditions were used in different tests (sets I, II, and III of table 2; pulse frequency was held constant at 8 pulses per second; voltage gradients used in each test are given in the text):

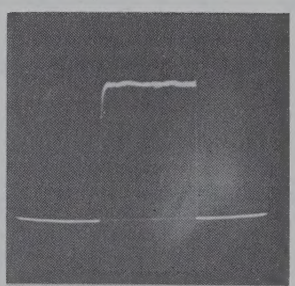
(I). Pulse direct current of "rectangular" configuration (fig. 4a) with a duration of 40 msec. (milliseconds). This set of electrical conditions was most effective in directing the movements of fingerling salmon in the laboratory (see footnote 2).

(II). Capacitor discharge pulses with a duration equivalent to that of a 40-msec. "rectangular" pulse (fig. 4b).

[4]The orientation and movement of fish in a direct current field to the positive electrode (anode) are well documented in the literature (see Applegate, Macy, and Harris, 1954).

Table 2.--Description of electrical conditions supplied to electrode arrays

Set No.	Electrical conditions			Relative d.c. component
	Pulse shape	Frequency	Duration	
		Pulse/sec.	Msecs.	
I	Rectangular pulse (d.c.).	8	40	100
II	Capacitor discharge.	8	100 (equiv. to 40 msec. rectang.)	100
III	Capacitor discharge.	8	50 (equiv. to 20 msec. rectang.)	50



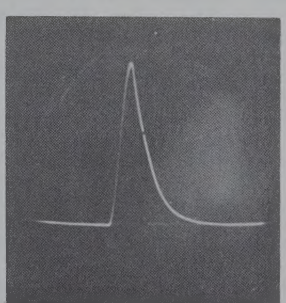


Figure 4.--Pulse shapes on oscilloscope, as used with three sets of electrical conditions in tests: 4a--rectangular pulse (d.c.) used with set I; 4b--capacitor discharge pulse used with sets II and III.

(III). Capacitor discharge pulses with a duration equivalent to that of a 20-msec. "rectangular" pulse (fig. 4b).

For all the tests reported here, water temperatures ranged from 17.1° to 18.1° C. and resistivities from 15,000 to 20,000 ohm-cm. Resistivity of the water was measured by an Industrial Instruments conductivity bridge, Model RC-1B.

The squawfish were taken by gill nets in Drano Lake, transported to Seattle in a fish tank truck on August 4 and 11, 1953, and held and fed initially in outdoor concrete rearing ponds at the College of Fisheries, University of Washington, Seattle. During the tests the fish were kept in wooden troughs at the BCF Biological Laboratory, Seattle. The 300 squawfish ranged in total length from 28 to 47 cm. (average, 36 cm.; 86 percent of the fish were 30 to 42 cm. long).

Exploratory tests were made to determine the combination(s) of electrode arrays and electrical conditions that warranted systematic tests.

An exploratory test consisted of 10 trials, each with a different fish, subjected individually to the electrical field. The initial behavior of the fish when it was first exposed to the field was recorded. A fish was recorded as blocked by the electrical field if it was deflected before entering the positive row of electrodes, or deflected out of the field after entering it, or immobilized within the field. We also noted whether a slight, moderate, or complete loss of equilibrium occurred before or after a fish entered the field, or after it passed through the field. Fish that were apparently unaffected by the electrical field or that showed very slight or moderate loss of equilibrium were retrieved as quickly as possible for use in later tests. We did not test the effects of length of fish on response to the electrical fields. At least 1 day elapsed between trials with individual fish.

TESTS OF ELECTRICAL FIELDS

Limited time and holding facilities precluded extensive testing of all possible combinations of electrode arrays with the three sets of electrical conditions. We made exploratory tests, therefore, to determine the combinations that warranted systematic tests.

Exploratory Tests

Various electrical fields were created by a combination of the electrode arrays (A, B, and C in fig. 2 and table 1) with the three sets of electrical conditions (sets I, II, and III in table 2) and two pulse shapes (fig. 4). The factors tested were:

1. Spacings of 30 and 61 cm. between electrodes in each row.
2. Parallel and staggered arrangements of electrodes in the two rows.
3. Distances of 100 and 200 cm. between rows of electrodes.
4. Voltage gradient.
5. The three sets of electrical conditions.

The effects of voltage gradients of 0.50 volt/cm. through 1.75 volt/cm. (at intervals of 0.25 volt/cm.) were explored at distances of 100 and 200 cm. between rows of electrodes.

Exploratory tests were made on (1) spacing and patterns of electrodes (tests 1, 2, and 3, table 3); (2) distance between rows of electrodes (tests 3 and 4, table 3); and (3) electrical conditions and wave form (tests 4, 5, and 6, table 3; figs. 4a and 4b). Pulse frequency was held constant at 8 pulses/sec. in all the tests.

Spacing and patterns of electrodes (tests 1, 2, and 3, table 3).--Electrode arrays A and B, each combined with electrical conditions of set I (rectangular pulse with a duration of 40 msec.--see table 2 and fig. 4a), were tested with voltage gradients of 0.50 through 1.75 volts/cm. (at intervals of 0.25 volts/cm.) and a distance of 100 cm. between rows of electrodes. Arrays A and B differed in numbers of positive and negative electrodes in the two rows, but in both arrays the electrodes were 30 cm. apart and the electrodes in opposite rows were parallel (tests 1 and 2, table 3).

The combination of array C (distance between electrodes 61 cm. and electrodes in opposite rows staggered, see fig. 2) and electrical conditions of set I (table 2 and fig. 4a) was tested with voltage gradients of 0.50 and 0.75 volts/cm., 100 cms. between rows of electrodes (test 3, table 3). The purpose of this test was to compare (with tests 1 and 2, table 3) the effects of the two voltage gradients when the spacing of the electrodes within each row was increased from 30 to 61 cm. and electrodes in the two rows were staggered.

Distance between rows of electrodes (tests 3 and 4, table 3).--The combination of array C with electrical conditions of set I (table 2 and fig. 4a) was tested with voltage gradients of 0.50 and 0.75 volts/cm. and a distance of 100 cm. between rows of electrodes (test 3, table 3), and with voltage gradients of 0.50 through 1.00 volts/cm. when the distance between rows of electrodes was increased to 200 cm. (test 4, table 3).

Electrical conditions (tests 4, 5, and 6, table 3).--Array C was combined with each set of electrical conditions and each combination was tested with voltage gradients at a distance of 200 cm. between rows of electrodes as follows:

1. The combination of array C and electrical conditions of set I was tested with voltage

gradients of 0.50 through 1.00 volts/cm. (test 4).

2. The combination of array C and electrical conditions of set II (capacitor discharge pulse [table 2 and fig. 4b] with a duration equivalent to that of a 40-msec. "rectangular" pulse) was tested with voltage gradients of 1.00 and 1.25 volts/cm. (test 5).

3. The combination of array C and electrical conditions of set III (capacitor discharge pulse [table 2 and fig. 4b] with a duration equivalent to that of a 20-msec. "rectangular" pulse) was tested with voltage gradients of 0.50 through 1.25 volts/cm. (at intervals of 0.25 volts/cm.) (test 6).

The voltage gradient of 0.50 volts/cm. apparently had little blocking effect on the adult northern squawfish when either array A or B (30 cm. spacing of electrodes, distance of 100 cm. between rows, parallel pattern of electrodes, see fig. 2) was combined with electrical conditions of set I (test 1 and 2, table 3). The blocking at this voltage gradient was more effective when the electrode pattern was staggered (array C; see fig. 2) and the spacing between electrodes in each row was 61 cm. and the distance between rows was 100 or 200 cm. (tests 3 and 4, table 3). When array C at 61 cm. spacing of electrodes in each row and a 200-cm. distance between rows of electrodes was combined with electrical conditions of set III, the blocking effect was the most effective at this voltage gradient (test 6, table 3).

The number of squawfish blocked at 0.75 volts/cm. closely approximated the numbers blocked at all of the higher gradients (table 3, tests 1 through 6). Above 1.25 volts/cm., immobilization and in many instances, subsequent death of the fish resulted.

Chi-square tests applied to the results of these exploratory tests at each of the voltage gradients indicated no significant differences among the various arrays and sets of electrical conditions in blocking the adult squawfish.

On the basis of the above tests, we eliminated the following from consideration for the systematic tests:

1. A distance of 100 cm. between rows of electrodes.
2. A spacing of 30 cm. between electrodes in the same row.
3. Voltage gradients of 0.50, 1.50, and 1.75 volts/cm.
4. Arrays A and B (because they required more electrodes than array C).
5. Sets I and III of electrical conditions (because set II--capacitor discharge, 8 pulses/sec. equivalent to 40-msec. "rectangular" pulse--has a wave form similar to the output of certain commercial devices used in fish screens and is more economical than pulsed current of "rectangular" configuration under field conditions).

Systematic Tests

The systematic tests were performed by the use of electrode arrays C, D, E, and F (table 1 and fig. 2), with capacitor discharge pulses at 8 pulses/sec. and a pulse duration equivalent to that of a 40 msec. "rectangular" pulse (set II of electrical conditions, table 2). At least five tests, each with 10 fish, were performed under each of the above combinations of conditions; voltage gradients used were 0.75, 1.00, and 1.25 volts/cm., and the distance between rows of electrodes was 200 cm.

Table 3.--Numbers of adult northern squawfish blocked in exploratory tests at indicated conditions, to determine conditions for systematic tests. Single fish were used in each of 10 trials.

Test no.	Electrode arrays[1] (see fig. 2)	Distance between electrodes	Distance between rows	Electrical characteristics[2]	No. of fish blocked at voltage gradient of:					
					0.50	0.75	1.00	1.25	1.50	1.75
		Cm.	Cm.	Set Number	No.	No.	No.	No.	No.	No.
1	A (P)	30	100	I	4	9	9	7	[3] 7	[3] 8
2	B (P)	30	100	I	3	8	8	8	[3] 8	[3] 10
3	C (S)	61	100	I	7	9	--	--	--	--
4	C (S)	61	200	I	6	10	10	--	(4)	--
5	C (S)	61	200	II	--	--	9	8	--	--
6	C (S)	61	200	III	9	7	9	10	--	--

[1] (P) = parallel; (S) = staggered.
[2] As indicated in table 2.
[3] Fish immobilized.
[4] Four fish tested--all immobilized.

The following results of the systematic tests are summarized in table 4:

1. Electrode array C appeared to be the most effective at all three voltage gradients: 85, 93, and 96 percent of the fish, respectively, were prevented from passing through the electrical field.

2. Electrode array D produced the most variable response in the adult squawfish at different voltage gradients. The percentages of adult squawfish that were prevented from passing through the electrical field were 58 percent at 0.75 volts/cm., 86 percent at 1.00, and 96 percent at 1.25. Electrode array D was thus as effective as electrode array C at the voltage gradient of 1.25 volts/cm.

3. Electrode arrays E and F produced similar responses in adult squawfish, and both were generally less effective than C (except for array F at 1.25 volts/cm.).

(4) Effectiveness for all four arrays increased with an increase in voltage gradient.

The results of significance tests applied to the data from experiments shown in table 4 were as follows (table 5):

1. The effects of the voltage gradients tested (0.75, 1.00, and 1.25 volts/cm.), for both parallel and staggered electrode arrays, were significantly different at an electrode spacing of 91 cm. (arrays D and F), but not at an electrode spacing of 61 cm. (arrays C and E).

2. With the staggered electrode array (C and D), the effects of electrode spacings of 61 and 91 cm. were significantly different at voltage gradients of 0.75 and 1.00 volts/cm., but with the parallel array, the effects of these electrode spacings were not significantly different at any voltage gradient.

3. Differences between electrode arrays C and D and between arrays D and F were not significant at any of the three voltage gradients or at either of the two electrode spacings.

CONCLUSIONS

The staggered array of electrodes--C, with electrodes spaced 61 cm. apart in each row and supplied with capacitor discharge pulses at a rate of 8 per second and a duration equivalent to that of a 40 msec. "rectangular" pulse--provided the most effective electrical conditions. Under these conditions 85, 93, and 96 percent of the adult squawfish were prevented from passing through electrical fields at voltage gradients of 0.75, 1.00, and 1.25 volts/cm. respectively.

The results reported in this paper are necessarily of an exploratory nature; the tests were performed under limitations of time, numbers of fish, and storage facilities for the fish. The data would be improved by (1) an increase in the number of tests and of individual fish in each test, (2) a larger range of sizes of adult squawfish, and (3) the use of smaller ranges of water temperature and resistivity.

Recommendation of an electrical barrier at the entrance to Drano Lake as a field site would necessarily depend upon successful experimental demonstration of the effectiveness of

Table 4.--Results of indicated systematic tests on the effectiveness of various electrode arrays combined with electrical conditions of set II in blocking adult northern squawfish (10 fish in each test)

Electrode array	Voltage gradient	Tests	Fish passing through field	Fish blocked	Percentage effectiveness
	Volts/cm.	No.	No.	No.	Percent
C	0.75	6	0-2	8-10	85
	1.00	7	0-2	8-10	93
	1.25	5	0-2	8-10	96
D	0.75	5	3-5	5-7	58
	1.00	5	2-3	7-8	76
	1.25	5	0-1	9-10	96
E	0.75	5	0-6	4-10	68
	1.00	5	0-4	6-10	82
	1.25	5	0-3	7-10	88
F	0.75	5	1-6	4-9	64
	1.00	5	1-4	6-9	82
	1.25	5	0-2	8-10	96

Table 5.--Significance tests on experiments (table 4) in blocking adult northern squawfish with electrical fields[1]

Voltage gradient	Electrode spacing	Electrode array	F value	Degrees of freedom	F (P = .95)
Volts/cm.	Cm.				
0.75-1.00-1.25	61	C	2.6426	2, 15	3.68
0.75-1.00-1.25	91	D	30.2401	2, 12	3.88
0.75-1.00-1.25	61	E	0.8723	2, 12	3.88
0.75-1.00-1.25	91	F	4.2586	2, 12	3.88
0.75	61 vs. 91	C and D	14.0570	1, 9	5.12
1.00	61 vs. 91	C and D	10.9103	1, 10	4.96
1.25	61 vs. 91	C and D	0.0876	1, 8	5.32
0.75	61 vs. 91	E and F	0.2294	1, 8	5.32
1.00	61 vs. 91	E and F	0.2506	1, 8	5.32
1.25	61 vs. 91	E and F	0.1797	1, 8	5.32
0.75	61	C vs. E	1.2216	1, 9	5.12
1.00	61	C vs. E	0.7460	1, 10	5.32
1.25	61	C vs. E	1.6213	1, 8	5.32
0.75	91	D vs. F	0.4921	1, 8	5.32
1.00	91	D vs. F	1.3008	1, 8	5.32
1.25	91	D vs. F	0.8479	1, 8	5.32

[1] These tests were applied to percentage data after transformation to: angle = arc sin $\sqrt{\text{percentage}}$ (Snedecor, 1950).

suggested electrical conditions. The following physical conditions at the entrance to Drano Lake, or other field site, should be surveyed and taken into account: (1) range in water temperature; (2) range in water resistivity; (3) fluctuations in water depth; (4) water flow; (5) width of channel; (6) bottom contour; and (7) depth at which an electrical barrier would not interfere with water traffic into Drano Lake from the Columbia River.

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